

DEVELOPMENT OF AN OYSTER CULTCH  
MATERIAL FOR THREE DIMENSIONAL  
OYSTER AQUACULTURE

John Walker Fisher

Thesis  
F4498



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by

JOHN WALKER FISHER

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Submitted to the Department of Ocean Engineering on May 14 in partial fulfillment of the requirements for the degree of Master of Science.

Off bottom oyster culture is clearly superior to any bottom oed techniques, however it suffers from the lack of a satisfactory cultch material. The recent practice by a large scale commercial oyster aquafarm of using hand punched scallop shells strung on a 1/8" nylon cord has resulted in estimated losses of 25-30% due to shell fracture and cord breakage.

Drilling was investigated as a possible means of increasing useful shell processing and decreasing post-stringing losses. Based on laboratory experiments, a 1/8" steel drill bit operated at 1328 rpm was found to be more efficient than either 1/4" or 7/8" drill bits operated at any speed. A net processing time of 20 shells per minute with a processing loss of 6.3% was possible using the 1/8" bit and drilling the shells one at a time. Group processing was considered, increasing successful output to 25.7 shells per minute with a processing loss of 18.9%.

A polypropylene-crushed scallop shell composite was also considered as a possible cultch and tests were made for abrasion and spat fall attraction. Abrasion was found to be of little importance. Spat fall was concluded to be a function of time after molding and surface texture. A commercially acceptable set was obtained in the laboratory by soaking the cultch in a 10% solution of fresh oyster shell liquor for three hours prior to 24 hour exposure.

Thesis Supervisor: Dr. Ira Dyer

Title: Professor of Ocean  
Engineering





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## INTRODUCTION

The commercial harvest of oysters in the United States has been falling steadily since the early 1900's.<sup>1</sup> Siltation caused by extensive dredging near many beds, ecological imbalance leading to a rise in predators, coastal pollution, over harvesting or mismanagement of natural beds, and increased processing costs without the requisite price increase are all possible, and probable, causes for the downward trend. If oysters are to play a significant role in alleviating the anticipated world food shortage of the future, better methods of oyster bed management and new techniques for improving population densities must be perfected now.

In the critical field of high yield aquaculture the United States is sadly lacking. Current yields (1968) of some of the worlds leaders in shellfish production are presented in Table [1]. Of the countries listed, only Japan produces oysters exclusively by off-bottom culture, though Spain and France are heavily involved in similar methods for cockles and mussels. The United States oyster industry obviously does not compare favorably with these countries. The dramatic difference is not attributed to climatic or environmental variation, but simply to the widespread application of the 17th century technology of off-bottom culture in Japan.

Before discussing the commercial potential of an organism, it is first advisable to understand its life cycle. Galtsoff's<sup>2</sup> monograph is a highly recommended source, although the American





TABLE 1

Aquaculture yield of cultivated stocks or natural populations with no fertilization or feeding. Units in fresh weight, shells excluded.

<u>COUNTRY</u>	<u>SPECIES</u>	<u>kg/ha/yr</u>	<u>t/acre/yr</u>
U.S.	Oysters (National Avg.)	9	0.004
U.S.	Oysters (Best Yield)	5,000	2.00
France	Flat Oyster (National Avg.)	400	0.16
France	Portugese Oyster (National Avg.)	935	0.37
Australia	Oysters (National Avg.)	150	0.06
Australia	Oysters (Best Yield)	540	2.20
*Japan (Inland Sea)	Oysters	58,000	23.30
Malaya	Cockles	12,500	5.00
France	Mussels	2,500	1.00
Philippines	Mussels	125,000	50.00
*Spain	Mussels	300,000	120.00

Source: The Status and Potential of Aquaculture. Volume I. Particularly Invertebrate and Algae Culture. John H. Ryther and John E. Bardach.

\* Calculations based on an area 25% covered by rafts.



oyster, *Crassostrea virginica* Gmelin is a well studied, highly documented creature.

The American oyster reaches sexual maturity at 10-12 months and may spawn any time conditions are favorable after that point. As ambient temperatures begin to rise above 20°C, gonads are developed and egg and sperm released into the water, independent of any mate. The eggs are fertilized outside the shell in open water. These will usually hatch within 48-96 hours, producing larvae which are free swimming for the first 20-25 days. At this point they metamorphose and set, attaching permanently to a handy solid object. The spat, as they are then called, lead a sessile life from this point on. Growth to marketable size depends entirely upon temperatures of the surrounding waters, though it may be stunted by nutrient unavailability. In Massachusetts, this growth period averages 4-5 years for wild, bottom grown oysters.

Shaw<sup>3</sup> charted the growth of oysters in Massachusetts as a function of both time and temperature. (Fig. 1) He found that growth was directly dependent upon ambient water temperature and that virtually no shell growth occurred when the temperature dropped below 10°C. The oysters were growing only 4 months a year, thus requiring 3 times as long to reach market size as similar oysters grown in tropic waters.

The justification for basing a large scale oyster farm in the cold Northern waters of Massachusetts is the higher quality oyster produced. During the winter months, when shell growth is



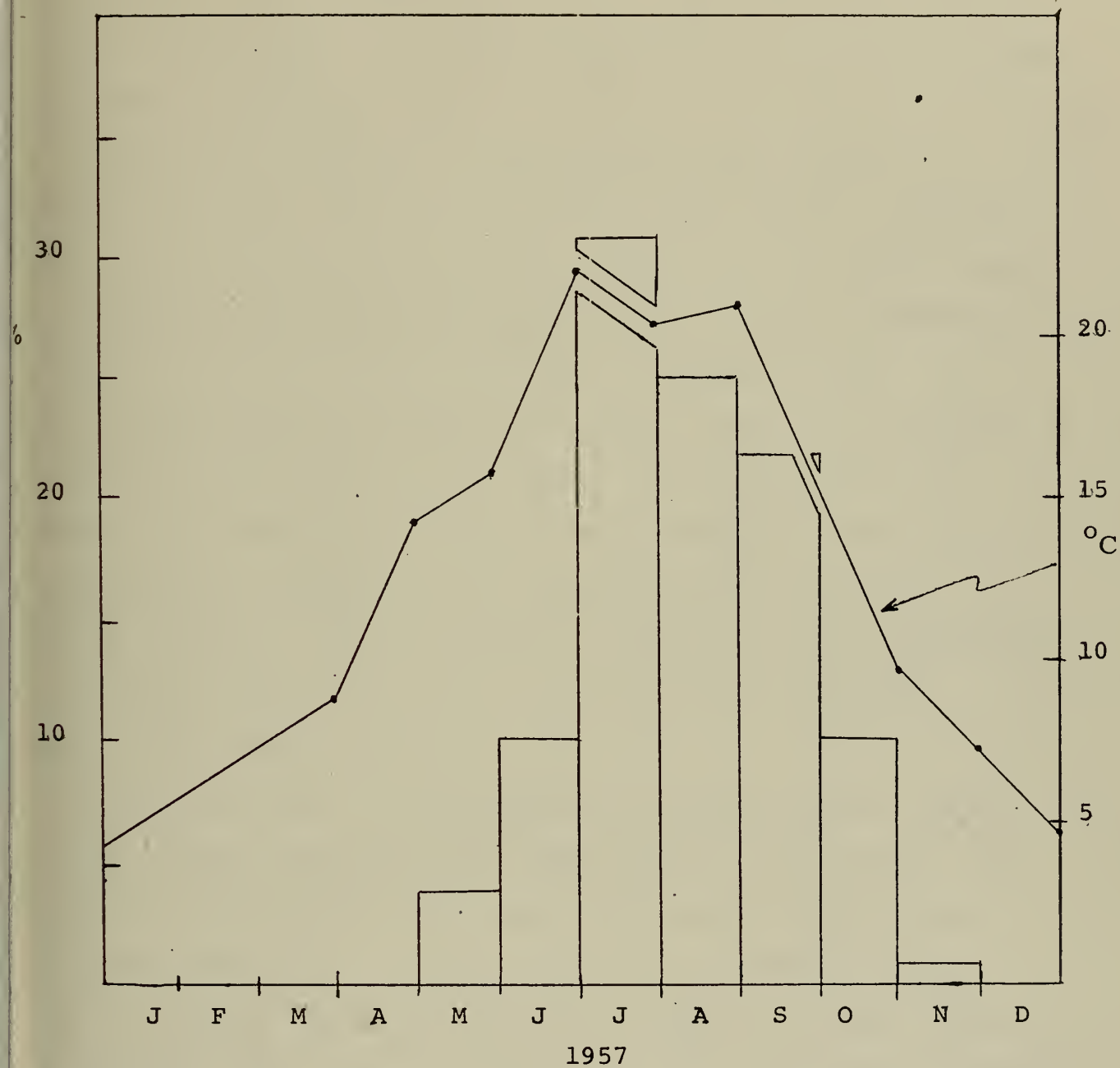


Figure 1 --Monthly increase in height and length of oysters as percentage of total growth during 1957. Temperature curve based on records taken at time of measurement.





retarded, the oyster adds fat or meat, improving the flavor considerably. This difference is quite noticable between the winter harvest oysters and oysters harvested any time of the year from warmer tropical waters.

Bottom bed management in the United States usually involves little more than planting young "seed" oysters, killing predators and harvesting the crop, although some intensive management programs do include thinning the beds to reduce crowding and careful control of silt build-ups. The seed oyster, are small oysters generally grown in a separate operation designed specifically to produce only immature oysters and their production is an industry in itself. Once purchased, they are scattered over a prepared bed of cleaned oyster shells, to build up the bed. The seed attach to the shells, are allowed one or two years growth, depending on area, and are harvested regularly by several methods.

Oyster mortality is quite high for bottom culture, running as high as 90% in some areas.<sup>4</sup> Oyster drills and starfish can decimate a bed in short order, and they must be carefully monitored and controlled. Siltation can easily suffocate large areas of oysters, and is particularly dangerous to young oysters. High pressure water jets or suction jets are often used to control this problem, as is frequent transplantation.<sup>5</sup>

Off bottom oyster culture probably began with the Japanese, who started collecting spat on upright bamboo stakes sometime in the late 17th century. While this method is still actively



used, most Japanese oysters are grown in raft culture. Wooden or bamboo rafts (50' X 60') buoyed by hollow drums are used to support 500-600 wires, each 30-40 feet long and strung with oyster shells on 7 inch centers. The wires, or rens as they are called once they are strung, are used to collect spat during spawning and then attached to the raft which is anchored in protected waters for the one year required to bring the oysters to market size. The rafts are generally quite crudely constructed and have a lifespan of only five years.<sup>6</sup>

Several United States growers have experimented with raft culture to gain the advantage of a high growth density, low mortality rate and ease of harvest. The results have been something less than overwhelming. In an Alabama study,<sup>7</sup> floating rafts were constructed of lumber, buoyed with styrofoam, and six foot long scallop shell rens were attached. Raft damage was slight in the protected bays of Alabama, growth was rapid, mortality was lower and the costs were prohibitive. To grow \$162 worth of oysters (18 barrels @ \$9/barrel) requires approximately \$347 in labor and materials. This includes a very significant cost of \$.75/ren or \$147 for stringing the 196 rens required to harvest 18 barrels of oysters.

A Massachusetts study in 1962<sup>8</sup> experienced considerable problems with raft-environment interaction, with particularly detrimental effects on the rafts. Raft damage and loss of rens due to storm conditions were significant factors in the loss of much of their raft-borne culture. Even so, 32 bushels



of oysters (worth \$368 @ \$11.50/bushel) were produced in two years, at a cost of \$248. The conclusions of the investigating team were generally favorable toward commercial raft culture, however, primarily as a means of exploiting the states' seed oyster potential.

A similar problem plagued an Oxford, Maryland study in 1970.<sup>9</sup> During the winter storms, most of the 1/8" nylon string being used in the rens were frayed by constant movement of the shells, resulting in the loss of most of the rens. The jagged edges of the punched holes in the shell were at fault. Damage to the rafts proper accounted for the remainder of the lost rens.

In a Georgia feasibility study,<sup>10</sup> shell erosion and growth retardation were found to be major drawbacks to raft culture. A high silt concentration and water current velocity were concluded to be the previous cause. These problems could be corrected by flow deflectors and obstructions, though this would increase raft cost. As it was, this study concluded that, due to high labor costs and low dockside price of oysters, raft culture was not economically feasible in Georgia.

In general, raft culture was not feasible in the South due to low prices and high costs, and in the North because of bad weather and cold waters. One factor not considered in either region, but of great importance in the United States, is the availability of large expanses of surface water suitable for raft culture of oysters. The high demand for coastal





waters for recreational sports places a high premium of those lands best suited for oyster raft culture.

A second Japanese method of culture is the long line system.

are moored 10-12 feet apart and connected by long, tarred rice ropes on which are hung rens spaced 3 feet apart. The primary advantages of this system are the low cost of construction and durability in rough waters.

This method has been quite successful in Japan, particularly in those waters where raft culture is unfeasible due to high wind or wave conditions. It has not fared quite so well in the United States, however..

In the 1962 Georgia study<sup>11</sup> previously described, a long line experiment was also initiated for a feasibility study. After four months of constant immersion, the rens had become hopelessly tangled. The primary cause seemed to be a dramatic increase in weight ascribed to rapid growth of fouling organisms. This brought the buoys closer together and allowed the rens to interact with each other. Efforts to increase the interval distance between rens and to anchor the buoys, more firmly were futile and the experiment was abandoned.



## OFF-BOTTOM REQUIREMENTS

In light of the previous discussion, three dimensional oyster culture in the Northern United States imposes two additional requirements on this system, peculiar to the area:

(1) Due to the lack of free coastal surface waters, the farm must utilize either very little area, or leave the surface free for other use.

(2) Special attention must be paid to environmental effects on the framework supporting the pens. Severe weather, high wind and wave conditions and winter ice must all be anticipated and designed for.

One possible solution is to compromise with both surface and bottom culture methods and place negatively buoyant racks on bottom. The advantages are clear:

(1) By placing a six foot high rack in 15-20 feet of water, the upper water column is left free for recreational use while still providing a three dimensional environment in the lower strata. The result is increased population density, higher growth rates, lower mortality and easier, predictable modular harvesting, with free surface loss held to a minimum.

(2) By removing the buoyancy requirement, a more stable configuration can be constructed of sturdier materials, such as steel or aluminum. The result is sturdier, more durable racks, more resistant to the marine environment.

(3) By placing them on the bottom, the racks are pro-



ected from surface waves and currents. The demonstration of this  
sing linear wave theory is included in Appendix I.

Such a system of steel racks, placed on the bottom are current-  
y in commercial use at Aquadynamics, a Marion, Massachusetts aquafarm.  
reliminary results from the initial harvest indicate a requirement  
or a higher strength stringing material and an improved cultch. In  
ll other respects the technique of submerged racks has proven to be  
n excellent one.

The Aquadynamics farming system employs steel racks measuring  
1'X 7' X 6' to suspend approximately 200 rens off the bottom. Each  
en is 5.0' long and contains 20 hand punched scallop shells, strung  
n a 1/8" braided nylon cord, separated by 3" spacers made of Poly-  
inyl chloride. The rens are strung by hand and suspended in Ocean  
ond to collect a set prior to being suspended on the racks. At the  
resent time over 900 racks are sitting on the bottom in Buzzards Bay  
epresenting an estimated 40,000 bushels of oysters.

After the three year period required to bring the oysters to  
arket size, the racks are winched aboard a special catamaran and car-  
ied back to a warehouse for picking, sorting and packing. The major-  
ty of Aquadynamics' market is for half shell oysters, hence no shuck-  
ng is required.

A number of minor problems have been e countered, primarily in  
he post-growing phases of operation. A better catamaran design is  
eeded to increase carrying capacity in stability. An automated  
eans of cleaning the shell exteriors, possibly by wet tumbling, would  
peed packing and reduce handling costs.





The major problem, though, has been with the durability of the pens. Cultch losses due to string failure and shell fracture are estimated at 25-30%. While these losses represent only a containment loss and not an absolute organism loss (the oysters are still live on the bottom), the higher mortality rate of bottom oysters and the need for a second harvest do represent an important cost increase. At the present time no plans have been made to recover these oysters, hence they represent a net loss of 25-30%.

The object of this project was to develop an inexpensive material which would reduce cultch related losses and still fulfill all peripheral requirements of a successful cultch. The cost and price figures quoted are taken from the production records of Aquadynamics, and thus represent true data from a large scale commercial operation. Only in this way could realistic cost limitations be applied.

To be successful, a cultch material must be capable of attracting commercially acceptable set, usually around 1-2 spat per square inch. Most of the work done on cultch development has centered on this aspect as a yardstick against performance. The requirements for good cultch range far beyond the simple one of attracting an acceptable set, however. In addition, in a subjective order of importance:

BIOLOGICAL RESISTANCE: The cultch must be relatively resistant to algae and other marine fouling organisms that may smother or crowd out the young spat, or must be capable of securing a quick set, without requiring long term immersion to season the material.



FIGURE 2



Hand punched scallop shell ren currently being used.



DURABILITY: Inertness to sea water and resistance to abrasion is very important. Since the rens will be immersed for three years without maintenance and subjected to continual wave action, durability is paramount.

STRENGTH: Tensile strength must be sufficient to support the weight of the matured oysters. Many otherwise acceptable materials are so severely stressed during processing that they cannot be used. A significant portion of the 25-30% loss figure for Aquadynamics can be attributed to shell failure.

COST: The original 1970 cost per ren was on the order of \$.35 with a near future projected increase to \$.40 due to additional costs of material acquisition. This has since been revised upward to its current estimated value of \$.48. A new cultch material with a 0% loss rate could cost as much as \$1.83 per ren without any loss in net income. (See Appendix II for cost breakdown and analysis.) A maximum cost of \$.80 per ren was chosen as an upper design limit to allow application of the cultch to areas where the price of oysters is considerably lower.

TOXICITY: Oysters are extremely efficient at concentrating trace pollutants, particularly harmful ones. Any toxins in the cultch that can be leached out by the sea water could easily be concentrated in the oyster meat, or kill the oyster.

REUSABILITY: With the current emphasis on ecology it behooves an investigator to consider the possibility of recycling the cultch or of employing a recycled material in its manufacture. There is also an obvious cost reduction advantage in using such materials.





WEIGHT: Weight is of importance primarily in the setting stage handling of the rens. The rens are gathered in bundles of 20 and placed by hand in Ocean Pond to secure the set. They must be held head high to prevent them from dragging on the ground, hence an arbitrarily established limit of 2 lbs. per ren or 40 lbs. per bundle was imposed. The bundle size could be reduced if necessary, though this would probably reduce the set density.





## DRILLING

The search for the ideal cultch has generally been centered around the necessity of collecting a heavy enough set to bring a commercial crop to harvest. For the present, scallop and oyster shells have been the most successful in attracting young larvae, and thus have been the most widely used. Their use, however, requires some means of suspending them, which in turn effectively requires a means of manufacturing a hole. The most popular means is simply punching a hole with a spiked hammer. While its inherent simplicity makes this method attractive, it also results in high shell losses due to immediate fractures (estimated 40-50%). More importantly, many shells are severely stressed and weakened by the process but do not actually fail until heavily loaded with oysters. The rough, uneven hole also tends to severely chafe the nylon string, causing further losses over the 3 year span of growth. Combined, these losses account for the 25-30% loss figure previously quoted.

As a possible solution, an attempt was made to drill the required hole through the shell. It was felt that a cleaner, neater hole would reduce stress fracture and reduce chafing losses. Three drills were tried, each from both sides of the shell. The raw data and procedure used are found in Appendix III.

The following conclusions were drawn based on this data:

- (1) The 1/8" diameter drill was far superior to either the 7/8" or 1/4" drills and represented a feasible means of manufacturing a hole.



- (2) There was no significant correlation between shell thickness as measured and ability to withstand drill processing.
- (3) Pre-sorting the shells is a desirable step in the processing chain of events to prevent wasteful processing of useless shells.
- (4) 1/8" group drilling has the potential of being an economically viable means of lowering current shell processing costs, and of providing a stronger, more reliable cultch.



### POLYPROPYLENE COMPOSITE

Alternative means of incorporating scallop shells into a cultch are also considered. The process envisioned entailed grinding the shell into an acceptable sized grit and using a binder to reform it in the desired shape. The natural choice for a binder was a plastic of some sort. There are several reasons for this choice. Plastic is cheap, readily available, lightweight, quite durable in sea water, non-toxic, has a high tensile strength and an advanced state-of-the-art manufacturing technology. The major drawback is its apparent inability to attract larvae, though there is conflicting evidence on this point.

The North Carolina Department of Conservation and Development conducted one of the few in depth field studies of both cultch materials and techniques in 1967.<sup>12</sup> They concluded that large (10" X 10") asbestos plates spaced 6" apart were superior to any combination of size and spacing using polypropylene either coated with Inertol ( a tarlike substance) or with imbedded sandspots. They were also superior to smaller asbestos plates of all spacings. The sandspot-embedded polypropylene was an acceptable material for raising seed oysters, the experimentors found, but that spontaneous detachment after a few months rendered it unacceptable for raising oysters to maturity. The plastics experienced an initially retarded set, but after being immersed for several weeks, a satisfactory set was obtained.

Loosanoff<sup>13</sup> also found polypropylene to be acceptable to spat, but difficult for maturing oysters to bond to. Again, spontaneous



attachment was a serious problem.

Both of these findings were in conflict with a 1962 study by the United States Marine Fisheries Service.<sup>14</sup> In laboratory selectivity tests, various cultches were tested in single competition against scoured oyster shells for collecting spat. Their results, presented in Table (2) show clearly that natural shell is much preferred to any synthetic material and that plastics (polystyrene in this case) are not satisfactory for collecting spat. To confirm the laboratory studies, field tests were carried out in the harbor waters of Milford, Connecticut. Several wire mesh sacks, each containing one type of cultch and representing several different materials, were spread randomly over the harbor during spawning season. Thus, the larvae were free to choose among any of the materials. The chart in Figure (3) demonstrates once again the desirability of natural shell, and the unsuitability of plastic, as a setting medium.

The combination of a rough scallop shell surface embedded in strong, durable polypropylene substrate was felt to be an ideal composite. The texture of the shell surface would be able to attract and hold the spat as they matured while the plastic maintained the cultch integrity without fracture problem.

To test the feasibility of constructing cultch in this manner, laboratory test specimens were developed and tested. Several variable parameters were investigated and their relative importance evaluated.

Various concentrations of scallop shell filler were mixed with





Table 2      Number of oyster spat on artificial collectors and  
oyster shells obtained under similar conditions in  
laboratory tests

Common name	Average number of spat per 6 sq. in.	
	Oyster shells	Artificial cultch
-phenolic resin	0	0
-vinyl plastison	abundant	0
-silicone rubber	35	0
-styrene/butadiene <sup>1</sup>	48	1
-styrene/butadiene <sup>2</sup>	131	1
-asphalt varnish	85	1
-vinyl-latex	16	1
-epoxy resin	284	1
-polystyrene	171	1
-acrylic resin	89	1
-air-drying vinyl resin	8.7	1.7
-natural rubber	86	2
-polyethylene	125	2.5
-polyester resin	103	2.3
-tire stock	246	13
-cement board <sup>3</sup>	187	37
-cement board <sup>4</sup>	487	49
-insulating cement	63	16
-neoprene	244	75
-rubber cement	114	56

<sup>1</sup>Dow Chemical Co.

<sup>3</sup>Asbestoboard, Johns-Manville

<sup>2</sup>Armstrong Rubber Co.

<sup>4</sup>Flexboard, Johns-Manville



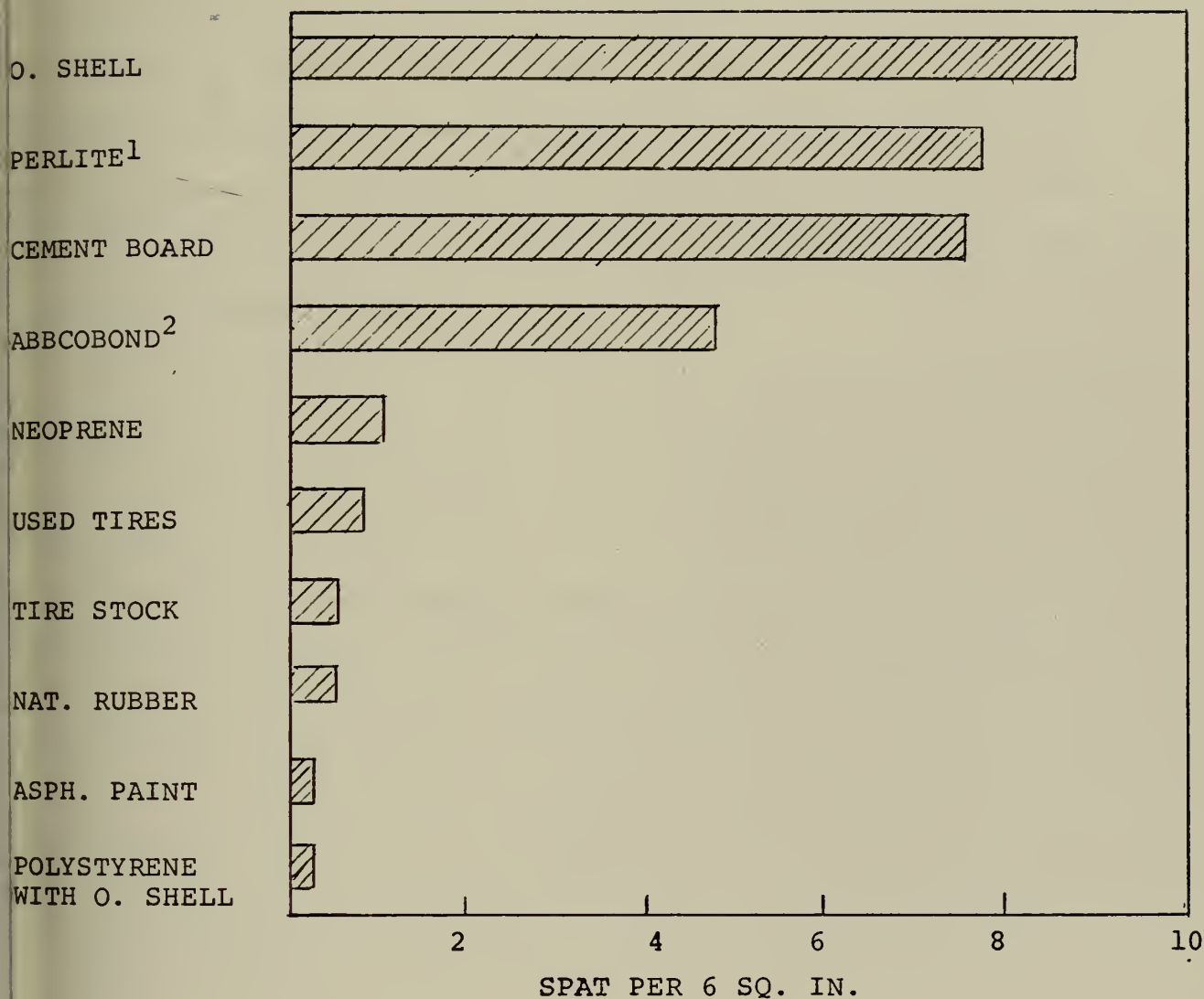


Figure 3. Number of oyster spat obtained on different materials under similar conditions in Milford Harbor, Connecticut.

<sup>1</sup>Perlite-insulating concrete made from cement and peruxalite, a volcanic glass.

<sup>2</sup>Abbcobond-black rubber cement.



Two types of polypropylene and hot compression molded using half-shell molds. Two methods of embedding the large shell grit into the clutch surface were also tested. The first, the so-called 1-step method, involved laying down a layer of grit in the mold prior to pouring in the polypropylene mixture. The second, the 2-step method, required pre-molding of a polypropylene-filler disk and reheating to embed the grit. Detailed procedures and raw data are presented in Appendix IV.



### COMPOSITE CULTCH EVALUATION

The durability of the composite surface was considered to be of significant importance, primarily in preventing the maturing of the cultch from spontaneously detaching or being jarred loose from the surface. Abrasion caused by constant movement in sea water was simulated in the laboratory by a temperature bath shaker. Six large disks molded from 5" diameter molds and evenly representing both methods of surface embedment were immersed in unfiltered sea water at 22°C and fixed to the shaker bed. The two different methods of surface attachment were placed in separate tubs in the same shaker.

The shaker bed described an approximately circular orbital path of 6" circumference and was operated at a frequency of 6Hz. Since this frequency of the shaker was well above the natural frequency of the water, the travel of the cultch represented a true velocity through the water of 3' per second.

The tubs were drained after 24 hours and filtered through #10 filter paper with the aid of a vacuum pump to retrieve any material loosened from cultch surface. An equal volume of sea water was filtered through another filter paper to obtain a background solids figure. The papers were dried and weighed, while the cultchs were returned to the shaker with a new volume of sea water for another 24 hours. The water was again drained and the dried





filter papers weighed.

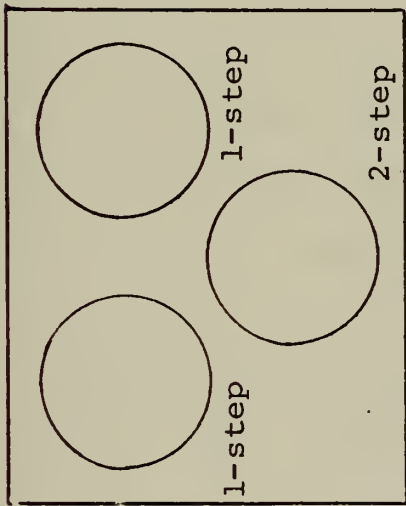
The difference between the filtered cultch water and the plain sea water was taken to be the weight of material lost from the disk surfaces. For the first measurement these averaged 2.3 grams per disk for the two-step group or .5 grams per disk for the one-step group, representing losses of approximately 2% and .4% respectively. The second measurement showed no appreciable surface grit in either tub.

Based on these results, there appears to be little concern over disintegrating surface texture. The velocity in the shaker was much higher than can be reasonably expected in the interior of the racks, where the oysters act as a break water. Mechanical abrasion caused by spacer-disk interaction was not considered, since no spat would survive if caught between the two and it was not considered likely that either one would totally degrade the other.

Although it was impossible to obtain a field set, a laboratory experiment was carried out with the help and cooperation of Mr. Warren Landers of the National Marine Fisheries Service. The six 5" disks used in the abrasion study, a number of scoured scallop shells and two freshly molded (2 days old) 3.5" disks were placed in three trays according to Fig. 4. Several thousand 3-week old larvae were added to the trays for 4 or 6 hour exposure. Three questions were considered:

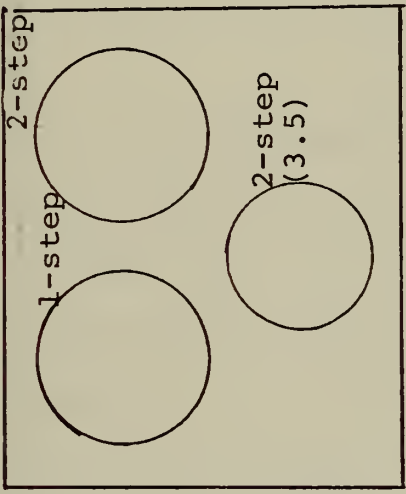


TRAY 1



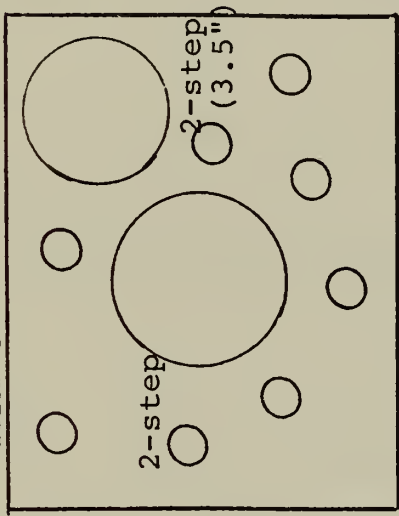
3-5" disks

TRAY 2



2-5" disks  
1-3.5" disk

TRAY 3



1-5" disk  
1-3.5" disk  
8-scallop  
shells  
concave side  
up.

Constant Temperature Bath  
(25°C)



- (1) How the composite cultch water rated against natural shell;
- (2) How the 1-step and 2-step cultchs compare;
- (3) The effect of 12 days immersion in sea water compared to fresh molding.

A brief examination of the data in Table (3) allows several observations.

- (1) Natural shell is very much preferred over the synthetic cultch. Based on Lander's work this was to be expected.
- (2) There seems to be some preference for the 2-step cultch, possibly due to a lower presence of plastic and more exposed shell.
- (3) Freshly molded plastic seems to have some toxic agent which must be leached out before setting will occur.
- (4) The sets obtained were well below acceptable commercial densities.

One possible way of improving the set on the composite is to take advantage of the gregarious setting nature of oysters, first documented by Cole & Knight-Jones in 1949. They noted that spat are more likely to set on shells where other spat have already set. A "setting factor" was partially purified by Veitch & Hidu and tested in a controlled laboratory experiment. By adding 10 ml. of FOSL (fresh oyster shell liquor) extracted from healthy oysters to 50 ml. beakers containing approximately 10,000 larvae, setting on uncoured oyster shells was increased by a factor of 1.35 to 5.61.

A crude experiment was conducted to test the ability of FOSL to induce setting on the polypropylene disk. Three disks used in previous tests were soaked in a 10% solution of FOSL for a period



TABLE 3

	<u>4/27/73</u> <u>4-hr. immersion</u>	<u>4/29/73</u> <u>6-hr. immersion</u>
<u>Pan 1</u>	<u>Spat</u>	<u>Spat</u>
Large 1 step	5	0
Large 2 step	8	2
Large 1 step	<u>2</u>	<u>0</u>
	15	2
Total area: $58.8 \text{ in}^2$		Total area: $58.8 \text{ in}^2$
Spat Density: $.25/\text{in}^2$		Spat Density: $.03/\text{in}^2$
<u>Pan 2</u>		
Large 1 step	10	1
Large 2 step	11	4
Small 2 step	<u>2</u>	<u>0</u>
	23	5
Total area: $48.8 \text{ in}^2$		Total area: $48.8 \text{ in}^2$
Spat Density: $.47/\text{in}^2$		Spat Density: $.1/\text{in}^2$
<u>Pan 3</u>		
Large 2 step	3 3	10
Small 2 step	<u>0</u>	<u>0</u>
	3	10
Total area: $29.9 \text{ in}^2$		Total area: $29.9 \text{ in}^2$
Spat Density: $.1/\text{in}^2$		Spat Density: $.35/\text{in}^2$
Scallop Shells (1)	35	7
(2)	29	4
(3)	3	52
(4)	174	22
(5)	135	139
(6)	<u>78</u>	<u>70</u>
	454	294
Total area: $42.6 \text{ in}^2$		Total area: $42.6 \text{ in}^2$
Spat Density: $10.7/\text{in}^2$		Spat Density: $6.9/\text{in}^2$





of 3 hours. The porosity of the cultch allowed penetration of the solution, enhancing retainment of the FOSL after withdrawal from the soaking bins. The treated disks were placed in a tray with several thousand larvae from the same group as was used in the previous setting experiments. Three disks exposed only to sea water were similarly exposed as a control group in a separate tray. The comparative results after 24 hours exposure were quite dramatic, as is evident from Table ( 4 ). The treated disks were able to obtain a commercially acceptable set without any difficulty, while the control disks secured approximately the same set density as before.



TABLE 4

	Total # Spat	Avg.	Avg. previous 2 tests
Control group			
(2 2-step, 1 1-step large disks)	5 top	.085	.14
	3 bottom	.051	(1)
Treated group			
#1 small	25 top	2.6	.1
	>25 bottom	>2.6	
#2 small	10 top	1.1	0
	50 bottom	5.2	
Large 2-step	50 top	2.5	.33
	20 bottom	1.02	
Totals	>180		
Total area	<u>77.8</u>		
	2.3 spat per inch		.19

NOTES

- (1) There was no appreciable bottom set in the first two tests, and no count was made. The figures thus reflect only the set on the top of the disks. The set in the third test was split approximately 50-50, hence, the bottom set could not be ignored. The probable cause for the discrepancy is the different length of exposure periods.



### DISCUSSION

Based on the results of tables (3) and (4) and experience in the laboratory, several observations are possible.

- (1) The cultches made by the 2-step technique appeared to be more successful than the 1-step cultch in attracting spat. They also provided a consistently rougher surface, discouraging spontaneous detachment of maturing oysters.
- (2) While the 2-step cultches suffered more loss in the abrasion test, the absolute quantities involved could be considered negligible. Abrasion by sea water was not a major problem in the laboratory.
- (3) A 50% filler concentration is the maximum desirable dilution if crushed scallop shell is to be used as the filler. It is recommended that a lighter, cheaper more readily available material be employed in this capacity.
- (4) The flake polypropylene with 30% glass fibre was superior in every way to the pellet form, at least as far as the methods utilized for molding were concerned. Designed as a special homopolymer modified for chemical coupling with glass, it proved to form a superior bond with calcium carbonate as well.
- (5) To prevent ultra violet ray damage from prolonged exposure to the sun, a pigment of some form should be added. The coloring of potash may or may not be sufficient to block appreciable UV damage. A one year constant exposure limit should be used as the time factor for design and test work.



Aquadynamics requires on the order of  $10^6$  disks per year to maintain their present operation. Any expansion would entail even greater quantities. The laboratory techniques used to manufacture the test disks were deemed unsatisfactory to meet this demand, even if carried out on a large enough scale.

- (1) Inconsistent quality of the disks produced was a serious drawback. This may have been more of a problem with equipment and execution of procedure than with the technique itself, however there was an unacceptably wide disparity of quality between sequential disks produced by the same method.
- (2) The time involved in individually molding each disk and the expense of producing the molds for the quantity required, would be prohibitive.
- (3) The processing of molding-cooling-reheating is a wasteful and time consuming one, but necessary to remove the disk and embed the crushed shell using the 2-step method. Re-expansion of heated disks where the pressure is released is also damaging to quality control efforts.
- (4) The wide difference in coefficients of thermal expansion between polypropylene and crushed scallop shell warped the thinner disks. The crush shell formed a tightly compacted surface layer on one side of the disk, while it was hot. As the cultch cooled, the plastic, with its higher coefficient of expansion, contracted much more than the compacted shell surface. The result was a convex shaped disk. While not considered to be a major drawback, such non-uniform effects may be an obstacle to automated stringing.





A more feasible means of mass producing the disks would require rolling out large sheets of polypropylene which are .05" thick. While still warm, these could be laid over a bed of heated shell grit and pressure applied by a large cookie cutter. This would embed the shell in the disk and form the disks including the hole, simultaneously. The excess plastic could then be returned to the melting pot for re-rolling into sheets.



### CONCLUSION

There are several good reasons for choosing a polypropylene composite cultch over natural shell.

- (1) Polypropylene is far less likely to fracture or to abrade the stringing material. Post setting losses of cultch can therefore be expected to drop considerably. The current program of strengthening the stringing material attacks only one part of the problem, increases the cost of the rens and has not been field tested.
- (2) Manufacturing the cultch provides uniformity of disks, thus enhancing the opportunity for automated stringing. By eliminating time consuming hand labor, it is expected that costs can be reduced significantly.
- (3) The entire quantity of shell paid for and transported to the stringing site is utilized. There is no loss due to pre-processing breakage or additional transportation costs for disposal of the unsuccessfully processed shells.
- (4) Coarse control of the spat fall may be possible through regulations of the pre-soaking mixture of FOSL. This would provide an adjustable prarmeter to prevent over crowding.

Should polypropylene be undesirable for any reason, such as prohibitive manufacturing costs, the utility of natural scallop shell can be increased several ways.

- (1) Drilling the hole with a high speed 1/8" drill will increase the processing rate while reducing processing losses.
- (2) Pre-sorting the shells will eliminate unnecessary and wasteful processing of broken shells.



- (3) Post processing testing will help spot non visible failures and reduce post-setting losses. This can be done by the stringer without any appreciable time loss.
- (4) Vinyl-coated wire should be considered as a possible stringing material to reduce losses from breaking strings.



## APPENDIX I

## WAVE EFFECTS ON SUBMERGED RACKS

According to linear wave theory, the velocity potential of a progressive water wave may be expressed as:

$$\phi = \frac{ga}{\omega} \frac{\cosh k(h-y)}{\cosh kh} \cos(kx - \omega t)$$

The horizontal particle velocity,  $u$ , may be written as:

$$u = \frac{\partial \phi}{\partial x} = - \frac{ga}{\omega} \frac{\cosh k(h-y)}{\cosh kh} \sin(kx - \omega t)$$

or, since  $c = \frac{\omega}{k}$ ,

$$u = - \frac{gH}{2c} \frac{\cosh k(h-y)}{\cosh kh} \sin(kx - \omega t)$$

but,

$$c = \left( \frac{g\lambda}{2\pi} \tanh \frac{2\pi h}{\lambda} \right)^{1/2} = \frac{gT}{2\pi} \tanh \frac{2\pi h}{\lambda}$$

Then,

$$u = - \frac{\pi H}{T} \frac{\cosh k(h-y)}{\cosh kh} \sin(kx - \omega t)$$

Since only maximum velocity conditions are of concern here, and phase is irrelevant, the sine term may be dropped without loss:

$$u = - \frac{\pi H}{T} \frac{\cosh k(h-y)}{\cosh kh}$$

The normal conditions for the Buzzards Bay area may be taken as a two-three second chop with a maximum wave height of two feet. Applying these conditions to the center of a structure six feet high located on the bottom in 18 feet of water (depth of interest equals 15 feet):

$$L = L_0 \tanh \frac{2\pi h}{L} = \frac{gT^2}{2\pi} \tanh \frac{2\pi h}{L}$$

At the surface:

$$L = 45.5'$$

$$\begin{aligned} u_{\max} &= \frac{\pi H}{T} \quad (y=0) \\ &= 2.09 \text{ ft/sec} \end{aligned}$$





## APPENDIX II

COST ANALYSISscallop Shell Ren

Initial costs of the ren was approximately \$.35, broken down as follows:

Materials

string-1/8" braided nylon cord	\$ .08
spacers-1/2"PVC tubing	\$ .05

Labor

punch hole & stringing(This is piecework.cost of punching the hole is estimated at ≈\$.02.)	\$ .15
tying off the ends	\$ .03
cut spacers	\$ .01
transportation of shell and strings	<u>\$ .04</u>
	\$ .35

The sudden demand for scallop shell in the Buzzards Bay area had the effect of elevating it from the role of waste material to economic resource, resulting in a rise in acquisition and transportation costs. The cost of the string also rose, primarily as a result of switching to 3/16" cord in an effort to reduce string loss.

As of 1May 1973, stringing costs stood as follows:

Materials

shell	\$ .10
-------	--------



string	\$ .10
spacers	\$ .07

Labor

stringing & tying (piecework)	\$ .15
cut spacers	\$ .01
transportation	<u>\$ .05</u>
	\$ .48

In addition to the stringing costs, a royalty fee of \$.20 per ren is charged by Ocean Pond to obtain the set. Thus, the current value of a ren on the rack is approximately \$.68.

Yield estimates from the first harvest at Aquadynamics indicate an average yield of nearly .25 bushel per ren, at a current market value of \$22 per bushel. From these figures a crude real-cost figure can be calculated for the cultch.

Value per ren = (.25)bushel per ren X \$22 per bushel =	
	\$5.50
Loss per ren = (.25) (5.50) =	\$1.35
Cost per ren =	\$0.68
Net profit per ren =	\$3.47
Total cost per ren =	\$2.03
Subtract royalty fee =	-\$0.20
Total manufacturing cost per ren =	\$1.83

Any reduction in this figure represents a net profit increase, and is most desirable. For the purpose of this paper, a ceiling of



\$1.00 per ren was imposed.

### Polypropylene Composite

Considering assembly costs to be fixed, as a first approximation, maximum production costs can be estimated.

Approximately .025 lb. per disk polypropylene was required for the 3.5" cultch. This represents a cost of .5 lb. per ren or, at a current bulk rate of \$.16 per pound, a cost of \$.08 per ren.

Potash, if used as the filler can be expected to cost less than \$.02 per string, mostly for transportation. The cost of the unprocessed scallop shell is difficult to estimate. Most purchases are made in units of dollars per pile, price being determined by non-standardized haggling. As an estimate, \$.04 per ren will be used.

Material costs, then, add to:

Maximum allowable cost	\$1.00
Labor cost	.21
Setting royalty	.20
Spacers	.07
Polypropylene	.08
Filler	.02
Shell	<u>.04</u>
Maximum production cost	<u>\$0.30</u>

This figure could probably be reduced at least two ways. Automated stringing at the manufacturing plant would reduce the labor costs considerably; and the use of a vinyl coated wire as the stringing material instead of 3/16" nylon cord could help reduce costs, while boosting reliability. The major cost increase will be additional



treatment costs to soak the disks in FOSL prior to securing the set.





## APPENDIX III

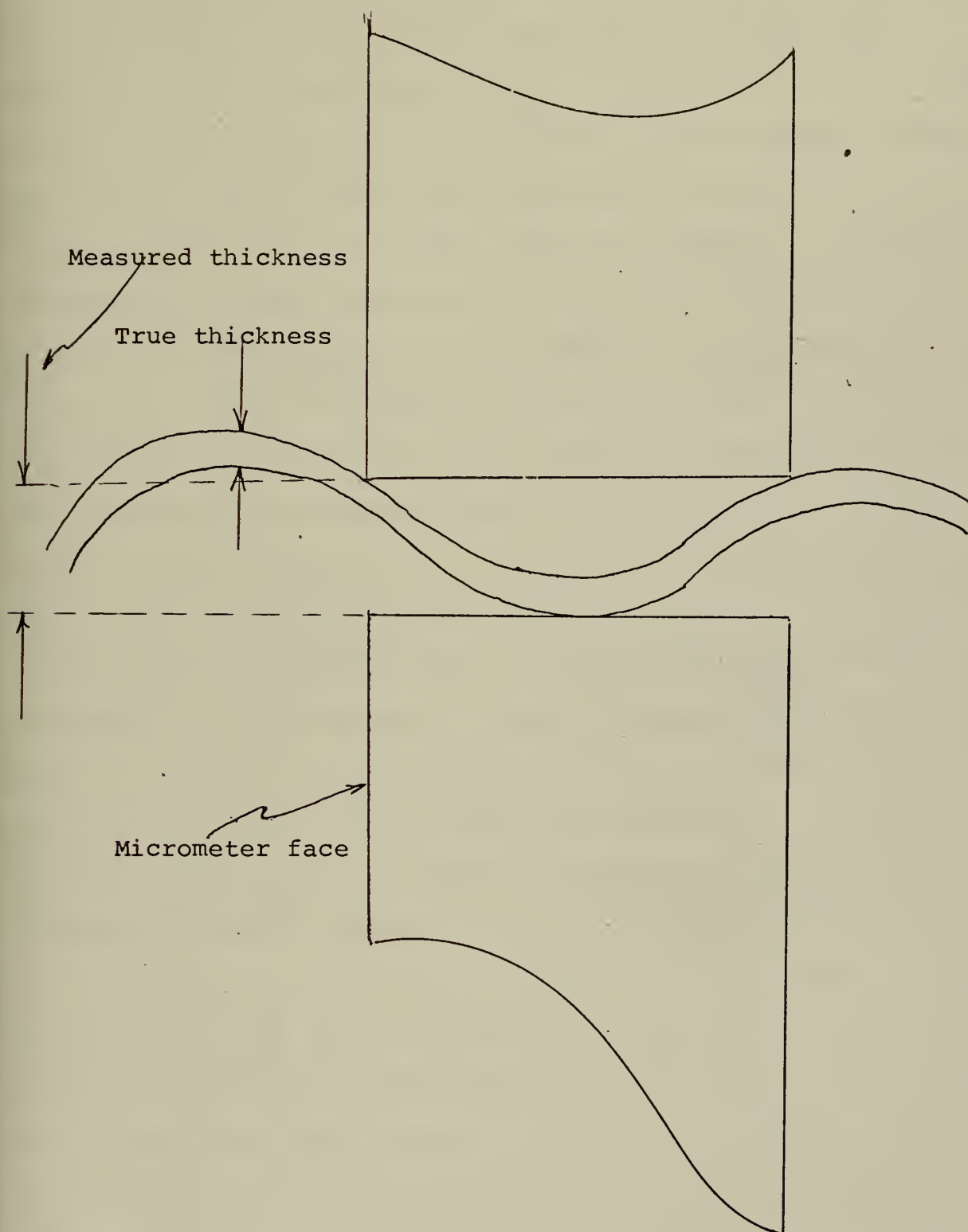
Drilling success was considered a function of four parameters: shell thickness, drill diameter, drill speed and side of entry.

In the initial test, a 1/4" steel drill bit was run at low speed (476 rpm) on a flat table drill press. Both convex and concave entries were attempted and recorded. Shell thickness and success were tabulated. The shells were presorted to remove any shells already fractured. After processing, the shells were tested by the application of a light bending moment. (1-2 in-lbs) as a check against non visible failures. The shell thickness was measured with a 1/4" diameter micrometer. This method was not totally satisfactory since it did not, in fact, measure shell thickness, but rather ridge depth as shown in Fig. (5).

The speed at which shells could be processed was considered an important factor in determining the economic feasibility of drilling. The number of shells successfully drilled over a two minute time span was used as a rough figure. It should be pointed out how very rough this figure really is. The experiment was carried out by an interested investigator concentrating on his task over a relatively short time in the artificial conditions of a machine shop laboratory. On the other hand, the investigator did not have the benefit of a work area designed specifically for the task (raised holding platform, strategically placed processing bins and comfortable seating would have helped greatly) nor was the investigator particularly well qualified to operate the machine in use. Without detailed field data from an established operation, there is no way to evaluate the effects



FIGURE 5



Non constant thickness measurement error due to surface irregularities.



f any of these parameters. The figures arrived at, however, can be useful as long as their inherent weaknesses are understood.

The 1/4" drill bit performed well in a majority of cases, though it shattered some shells and set up serious stress fracture patterns in many others. These stress lines appeared as thin white lines spreading from the point of contact and were visible to the naked eye.

An attempt was made to evaluate stress fracture patterns using X-rays from a standard hospital X-ray machine. This attempt failed apparently due to the very small differential thicknesses involved.

The process of drilling the hole seemed to involve two steps. In the first stage, the base of the bit actually cut or abraded the shell, widening the hole to the outside diameter of the bit shank. Except for very thin shells, there were few failures at this stage. The second stage was entered after the drill shank broke through, causing the majority of failures. The unsharpened edges of the shank appeared to catch the interior edges of the hole, tearing away large chunks of material and causing significant stresses. The result was either large jagged holes or fractured or shattered shells.

The possibility of using a larger drill was considered as a means of reducing or eliminating the fractures attributable to shank break-through. A 7/8" drill was run at 476 rpm and depth limited to prevent the entire face from penetrating the shell. This provided a means of using only the cutting face and not the shank. Entry was attempted from both sides of the shell.

The preliminary results were very encouraging--losses dropped to approximately 30%. The quality of the hole also dropped, however with a large number being very jagged or seriously stressed. The



technique's success was also a function of time spent per shell. As processing rate increased, so did shell fracture. The data presented in Table (5) was the optimum speed from the results (highest successes per unit time). At this speed, (9.3 holes per minute), the cost is too high.

The final effort was directed at reducing the hole size, thus limiting the effect of the drill on the shell. Working on the assumption that a vinyl coated wire (O.D. .1") is an economically sound proposition as a string material, a hole size of 1/8" would be sufficient to accomodate it. Tests were run first on single shells at low speed (476 rpm). The results were encouraging enough to warrant further tests. Drill speed was raised to 1338 rpm, improving results slightly, as shown in Table (5). The processing time was also reduced. Group processing was attempted as a possible means of speeding up the process still more. The shells were scattered on the bench as before, but prior to drilling were stacked in groups of 4-6 and drilled simultaneously. Stacking time was included in the net processing time. Only convex entry was attempted.

A maximum speed of 25.7 successful holes per minute was possible using this technique. Approximately half of the shells rejected were processed successfully except for an offset of the hole. Many of the hand punched shells were similarly mispunched, but were strung anyway without any apparent consequence. Considering those shells with misplaced holes as being acceptable, the successful processing rate exceeded 28.7 holes per minute.

Since there are no data available on the current practice of hand punching the holes, no efficiency or cost comparisons can be







ade. The figure of \$.02 per ren for punching presented in appendix II seems to be quite low. This figure represents a success rate of 26.7 holes per minute, based on a \$1.60 hourly wage. A more reasonable figure would probably be in the range of 15-20 and may be as low as 10-15 without presorting. On this basis, it is safe to conclude that drilling has a definite potential for increasing shell reliability and decreasing cost.



FIGURE 6

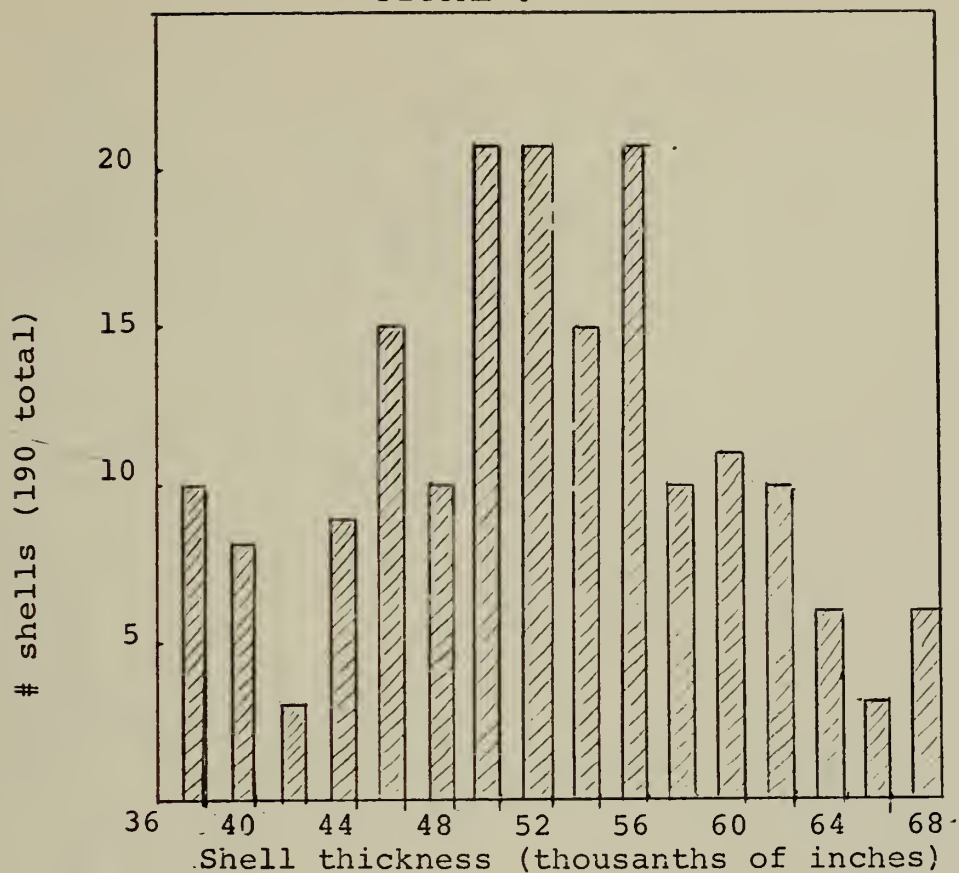
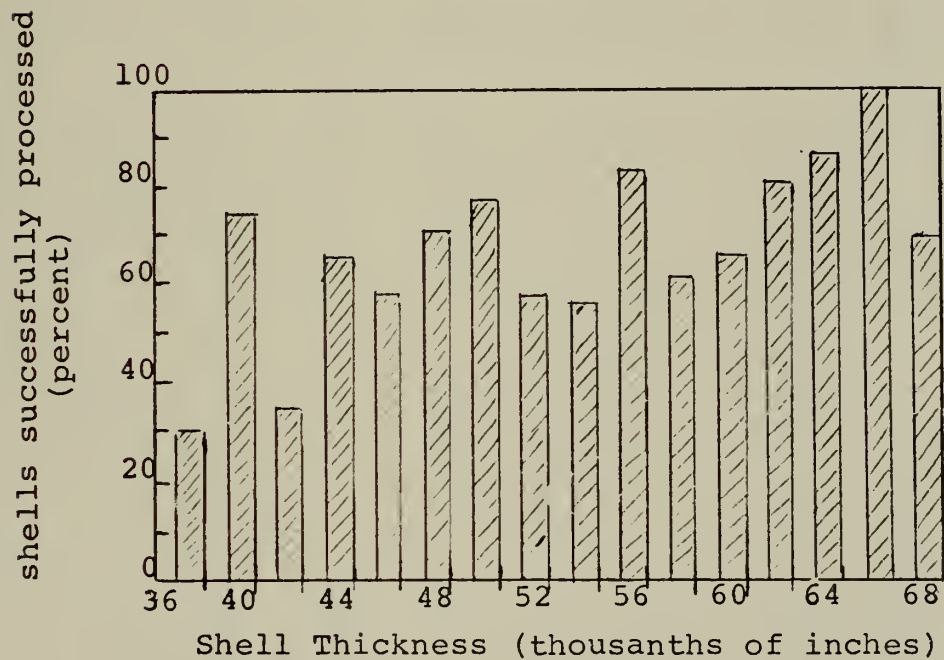
SHELL THICKNESS DISTRIBUTIONSHELL DISTRIBUTION OVER SHELL THICKNESS



TABLE 5

	AVG.						RATE		
	F %	SS %	S&MS %	R&J %	MP %	# SHELLS	THICKNESS %	% NA %	(success/min) %
H.S. 1/8"X	6.3	0	9.4	12.5	---	32	52.1	6.3	-----
H.S. 1/8"V	3.2	6.5	19.4	41.9	---	31	50.6	6.5	-----
L.S. 1/8"X	6.3	0	21.9	15.6	---	32	51.5	6.3	-----
L.S. 1/8"V	0	12.5	46.9	50	---	32	49.9	6.1	21.2
H.S. 1/8"XG	7.7	1.5	9.2	13.9	7.7	65	52.8	15.4(7.7)	25.7(28.3)*
	F/S %	FP %	J&R %	SS %	MS/S %	C. %	#SHELLS	AVG. THICKNESS %	RATE (success/min) %
L.S. 1/4"X	20	8	32	12	32	4	25	32	49.5
L.S. 1/4"V	20	4	28	4	56	4	25	28	50.0
L.S. 7/8"X	19.4	9.7	22.6	3.2	22.6	9.7	31	32.2	55.4
L.S. 7/8"V	14.3	2.9	20	2.9	40	2.9	35	25.7	50.6
Unsorted									
L.S. 1/4"X	18.4	42.1	31.6	2.6	55.3	7.9	38	52.6	8.1
L.S. 1/4"V	20	27.5	27.5	7.5	30	0	40	60.5	52.3
X=convex side entry	H.S.= high speed (1338 rpm)								
V=concave side entry	L.S.= low speed (476 rpm)								
Shell disposition	Pre-broken			Undersized			Processing failures		
Group I	18.9%			14.9%			28.8%		
Group II	24.6			5.8			7.3		
							37.4%		
							62.3		



## NOTES OF TABLE ( 5 )

F	Fractured (See fig. 8-A )
SS	Seriously stressed (See fig. 7-D )
S&MS	Stressed or minor stressed (See fig. 7-B )
R&J	Rough or jagged (See fig. 7-C )
MP	Misplaced
F/S	Fractured or shattered (See fig. 8-D )
FP	Failed under pressure (post processing testing)
C	Weak center (See fig. 8-C )
NA	Not acceptable

\* Figures enclosed in parenthesis indicate values if misplaced holes were considered acceptable.





FIGURE 7

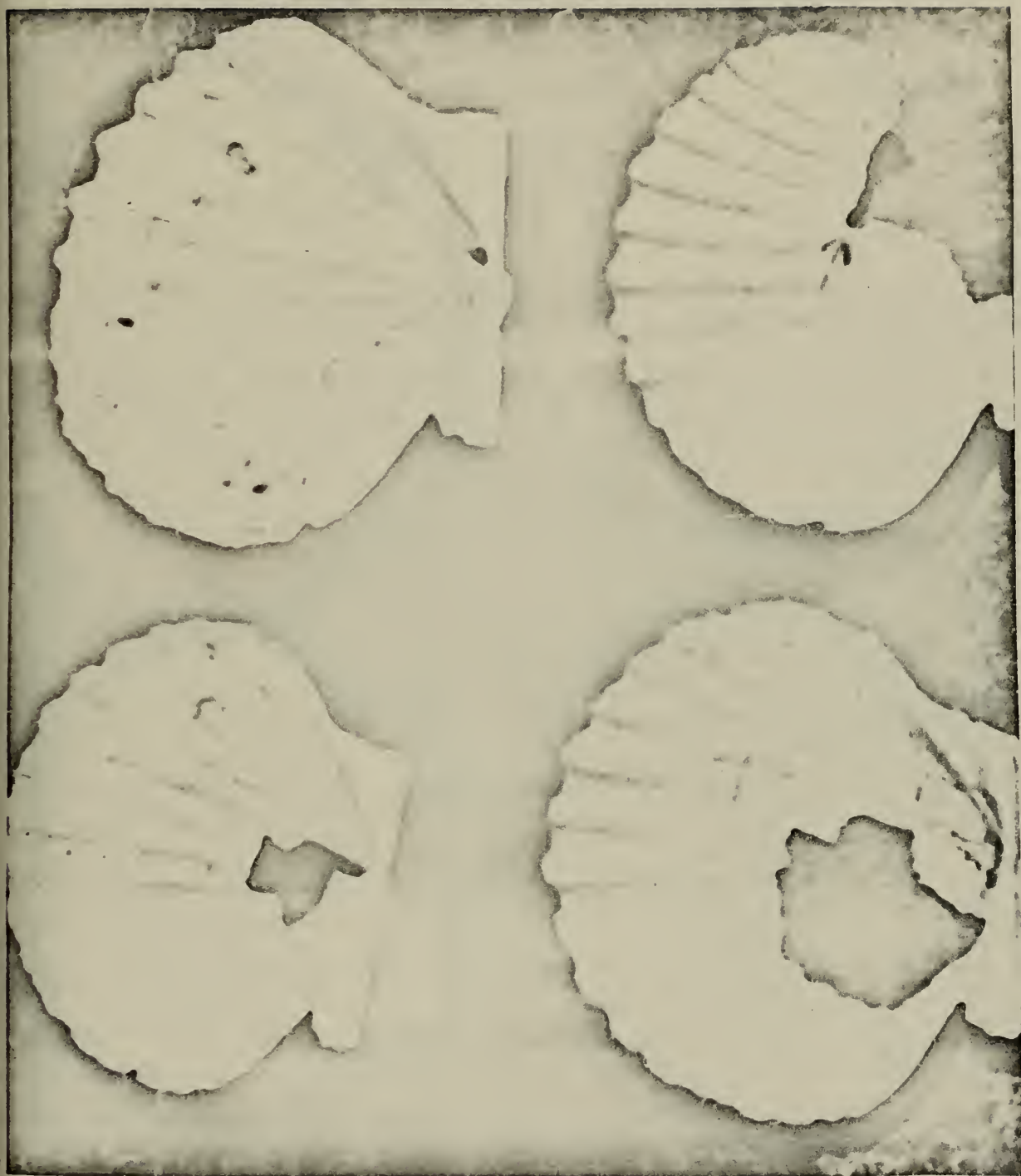


b. 1/8" stressed  
d. 1/8" SS

a. 1/4" rough  
c. 7/8" jagged



FIGURE 8

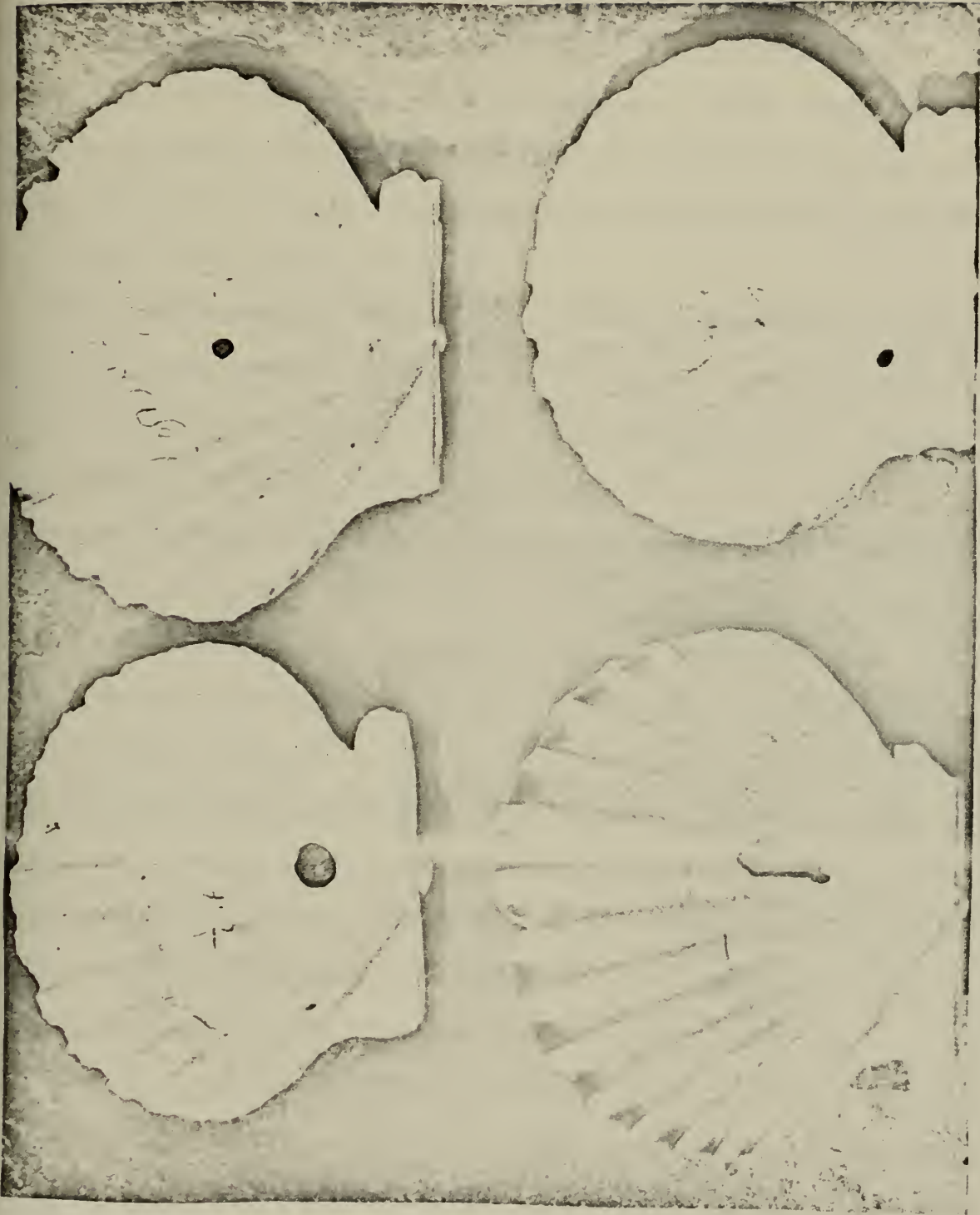


b. Prebroken (NA)  
d. 1/8" shattered (NA)

a. 7/8" J, MS (NA)  
c. Weak center (NA)



FIGURE 9



a. 1/4" acceptable  
c. 7/8" MS, J

b. 1/8" acceptable  
d. 1/8" convex-group, misplaced hole  
(NA)





## APPENDIX IV

Scallop shells were broken by hand into small ( $1/4"$  X  $1/4"$ ) pieces and rolled in a 1 gallon ball mill for several hours. The residue was sifted through a #20 mesh sieve (.0328" opening) and then through a #8 mesh sieve (.093" opening) to separate powder, acceptable grit and unground pieces. The powder was used as filler and the grit was reserved for surface coating.

Before constructing test disks, it was first necessary to determine the best method of manufacturing them. Hot compression molding using powdered polypropylene was decided upon, principally because of the availability of apparatus.

Molds for the initial test bars were milled from .5" brass stock to provide a 6" X 2" X .125" inset. Later molds were cut on a lathe from .5" aluminum stock in the shape of a 5" diameter disk and later a 3.5" diameter disk. All molding surfaces were coated with Frekote 33 mold release solution to facilitate removal of the molded material.

Two types of polypropylene were tried as binders: Hercules grade 6523, a pellet form with a tensile yield strength of 4900 psi and Hercules grade PC 072, a special grade flake with 30% glass fibre and a yield strength of 15,000psi. The powdered grade PC 072 was found to be superior for the type of molding employed. It formed a more compact, stronger cultch with more shell on the surface than the pellet form. This was probably more a function of the molding technique than the material itself. The flake grade PC 072 was used in all experiments reported here.

Polypropylene was dry mixed with powdered scallop shell on a





percentage weight basis and poured into the molds, which were preheated to 450°F. Powdered scallop shell was used as a filler primarily because of its availability, as a necessary byproduct of the ball mill processing for surface grit. It is anticipated that in commercial production more efficient means of grinding the shell could be utilized, and that potash, or some similar low cost, low density material would be used as a filler. The result would be a lighter, cheaper cultch.

Various filler concentrations were tried, starting with 30% filler, 70% polypropylene and going as high as 65% filler. While no quantitative measurements were made, qualitative judgements based on flexibility and fracture strength indicated a 50-50 mix was the highest filler concentration consistent with strength requirements.

After the mixture was heated in the mold for a minute, to bring it near flow temperature, the press was closed and subjected to 80psi for a period of 7-9 minutes. Excess plastic flowed out between the mold and the top plate. After heating, the pressure was released, and the mold placed in a tub of cold water. Removal of the molded disk took place as soon as it was cool enough to handle. Releasing the pressure while the plastic was still at flow temperature allowed re-expansion, resulting in a plate thickness 30-60% larger than designed for. This also had the effect of decreasing the density and increasing the porosity of the disk.

Two methods were tried for embedding the surface grit into the face of the disk, differing only in the point at which the surface grit was attached. In the first, referred to in the future as the two-step method, a thin layer of shell was laid down in the mold before



he plastic mixture was added. The 2-step method required that separate manufacture of a plastic filler disk which was cooled and placed over a thick bed of heated shell gut. Pressure was applied for 2-3 minutes to imbed the shell in the lower surface.

The first prototype molds were 5" diameter disks milled to a 1" depth. Six prototypes were eventually produced from these molds and later used in abrasion and selectivity tests. It was felt that a smaller, thinner disk would be better, hence two 3.5" disks were milled to a depth of .05".

The argument for the smaller disk is an obscure one. There is disagreement as to the characteristic dimension relating cultch size to oyster production. Results from Marshall would indicate that setting area characterizes oyster production. Some commercial growers, however, feel that the setting perimeter, not area, is the limiting dimension. That is, that the oysters grow radially, requiring a set amount of arc length for uncrowded growth, regardless of the radial length. While this has not been confirmed by the scientific community, it is worthy of note.

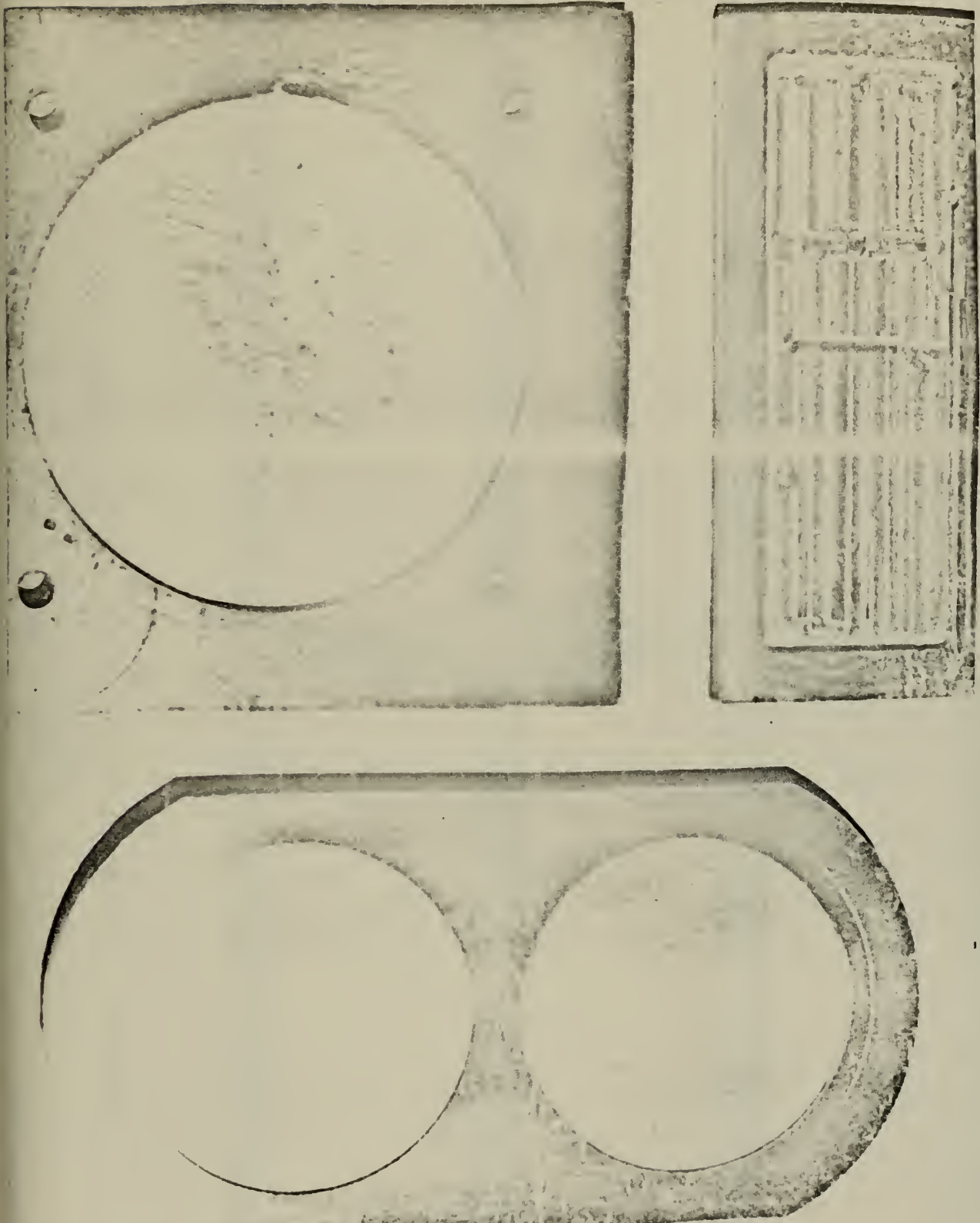
A more obvious reason for reducing the cultch size is to prevent oyster interaction. The spacing between racks is around 6-8", hence a 5" disk leaves little room for sway. The figure 3.5" was arrived at by considering another of Marshall's findings. His results clearly indicate that the most desirable spacing between disks is approximately 3.5". Since the rack length is restricted by rack size, increasing the spacing requires decreasing the number of disks. By increasing the spacing size to 4", 15 disks can be strung. This requires a diameter of 3.49" to conserve setting area, hence the 3.5" diameter chosen.



Using  $r$  as the characteristic dimension, instead of  $r^2$  (perimeter, rather than area), a net loss of 7.5" per string or  $\approx 12\%$ , will result from this arrangement.



Fig 10



Half Molds used to manufacture test elements.  
Flat plates were placed over the molds to enclose the volume.

a. First 5"X1/8" disk

b. 6"X2"X1/8" brass bar mold

c. Two 3.5"X.05" molds





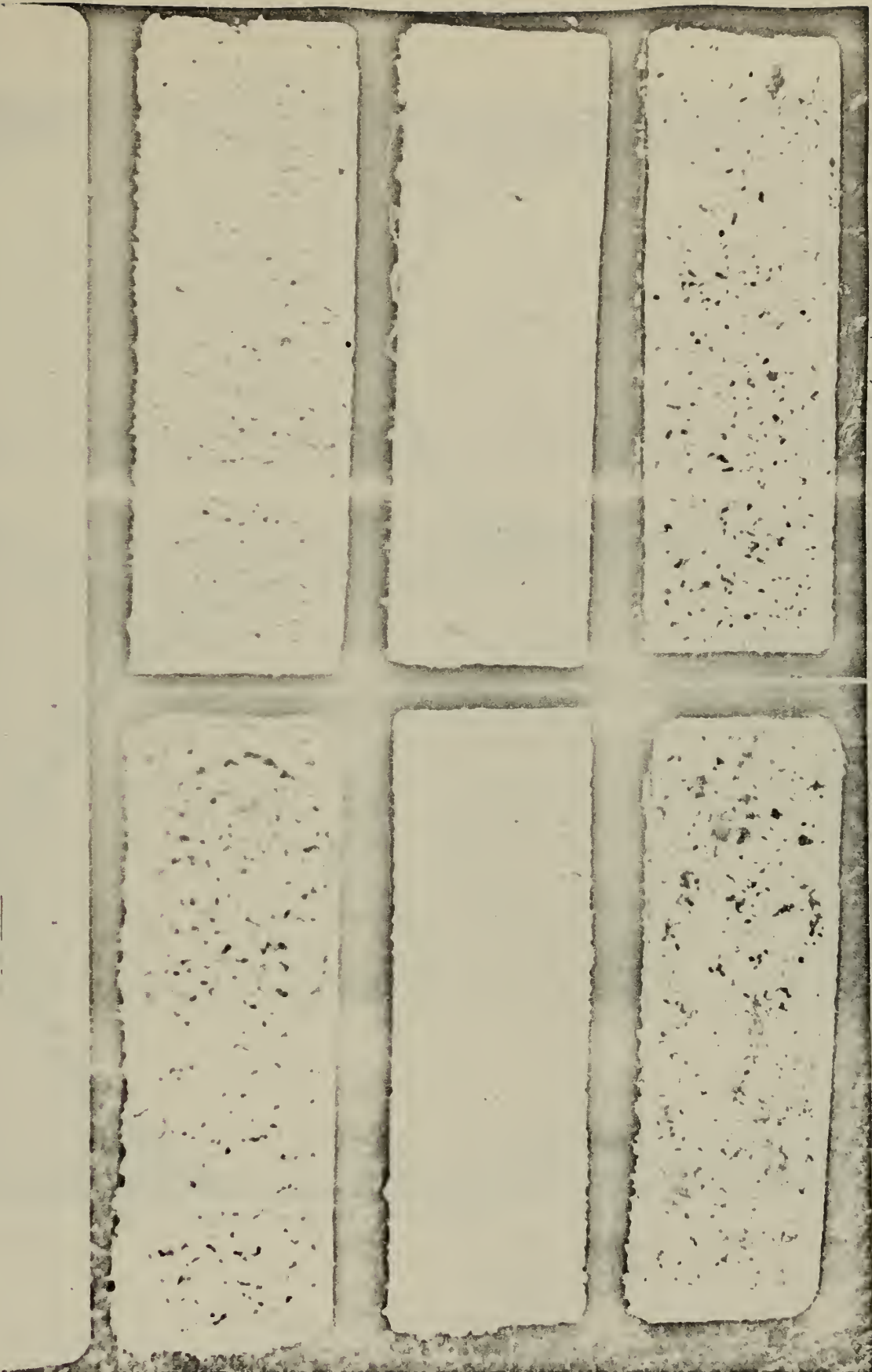


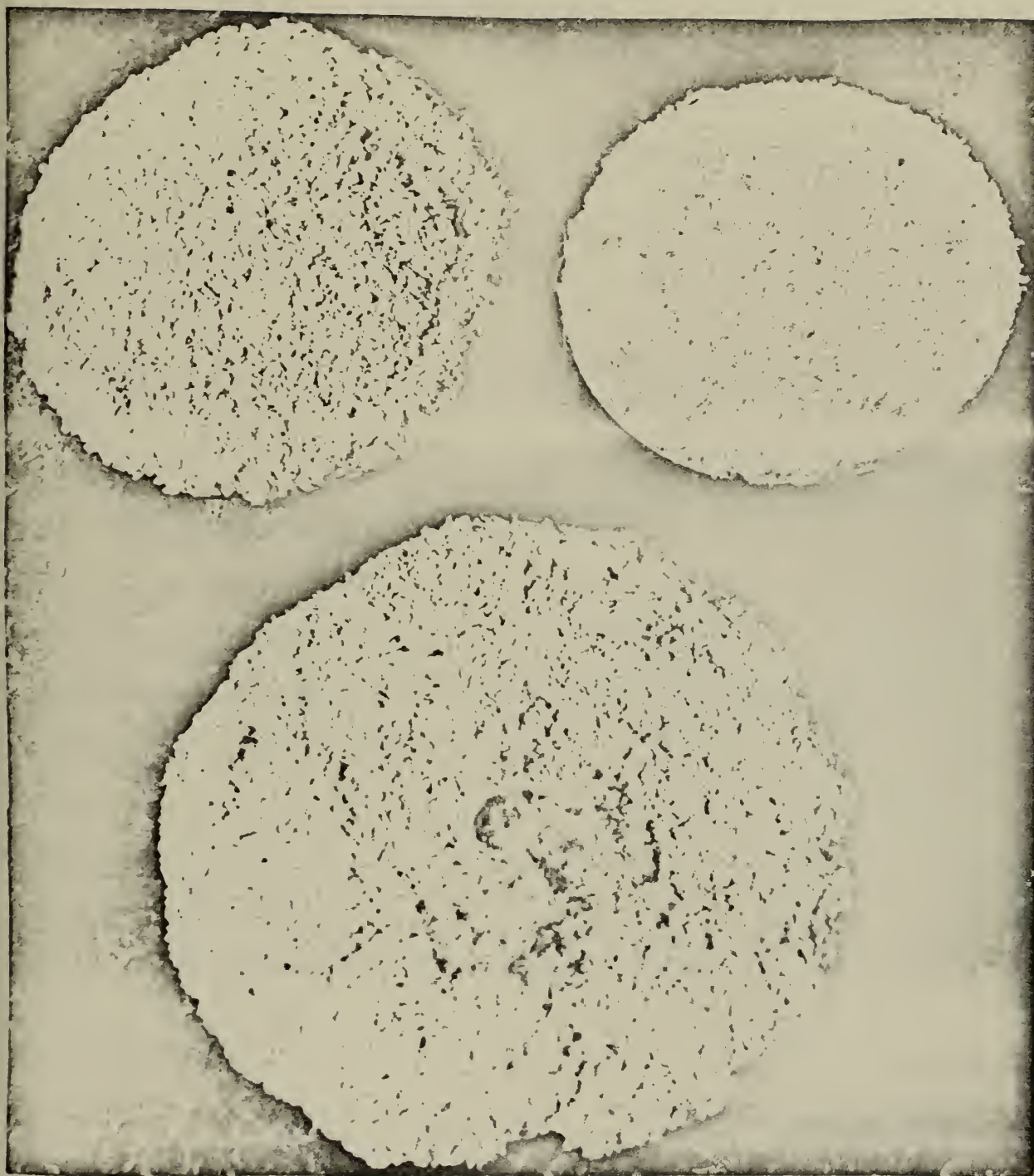
Fig 11

Molded test bars used to perfect filler concentration and molding techniques

- a. 2-step & 1-step 0% filler
- b. 2-step & 1-step 65% filler, powder surface
- c. 2 step & 1-step 50% filler, grit surface



FIGURE 12



Finished disk cultches

a. 3.5" 2-step

b. 3.5" polypropylene disk,  
prior to embedding surface  
grit.

c. 5" 1-step. early prototype



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Thesis  
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Fisher  
Development of an oys-  
ter cultch material for  
three dimensional oyster  
aquaculture.

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